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# Red Squirrel Distribution And Habitat Use In Illinois

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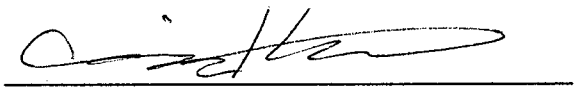

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## ABSTRACT

The North American red squirrel (*Tamiasciurus hudsonicus*) is a species of special concern in Illinois due to its restricted geographic range and low numbers. This species occupies a broad geographic range in North America and is usually associated with the boreal forests of Canada and coniferous forests in the Rocky Mountain range. The squirrels also occupy deciduous and mixed deciduous-coniferous forests in the eastern U.S. In Illinois, available habitat is suboptimal, and limited to pine plantations and small tracts of deciduous forest embedded in an agricultural matrix landscape. Information on the spatial distribution of red squirrels in northeastern Illinois was lacking until this study. In addition, little research had quantified resource selection of red squirrels in these habitat types. My study was designed to investigate and quantify summer habitat use of red squirrels at multiple spatial scales, ultimately contributing to the successful management of this population. The main research objectives for my study were to: (1) determine habitat use and preferences of Illinois red squirrels, and (2) delineate the current distribution of this species in the state.

Trapping and radiotelemetry occurred from May-August 2006 and 2007 at Iroquois County State Wildlife Area in northeastern Illinois. Home ranges were calculated and habitat preferences determined for 38 individual squirrels. The size of home ranges for all squirrels averaged 1.7 ha (SE = 0.24) and mean core area size was 0.4 ha (SE = 0.06). A $X^2$ goodness-of-fit test and compositional analysis were performed at both the $2^{nd}$- and $3^{rd}$-order selection levels. Results indicate that within the study site, deciduous forest was preferred and within home ranges, pines were used frequently. Key habitat components appear to be mast-producing walnut or pine trees, a dense understory,

snags, and downed wood. Red squirrels in this region did not exhibit territorial behavior and scatterhoarded their food items. These animals also spent considerable time on the ground foraging in thickets and dense understory.

To better delineate the current geographic range of red squirrels in Illinois, I conducted extensive phone and email interviews, posted public notices, and conducted acoustic point count (playback) surveys. My research suggests that Illinois red squirrels have a broader distribution than previously documented. In addition to inhabiting large tracts of deciduous forest, red squirrels were also found in small, isolated patches surrounded by grassland and agricultural fields. Results indicate that on a regional scale, highways, rivers, cities, cropfields, and grasslands are not barriers to the dispersal of red squirrels. Primary movement corridors appear to be along the Kankakee and Iroquois rivers and their tributaries.

# INTRODUCTION

## Natural history of red squirrels

North American red squirrels (*Tamiasciurus hudsonicus*), commonly referred to as pine squirrels, play an important role in the function of forest ecosystems. These diurnal animals are active year-round and have the ability to impact forest structure and regeneration. By collecting and burying seeds in food caches during preparation for the winter season, red squirrels act as seed dispersers. Smith (1968a) observed that red squirrels may cache up to 16,000 cones of white spruce per year. Red squirrels also serve as important prey for many species, including snakes, raptors, and several mammalian carnivores, notably the marten (*Martes americana*) (Steele 1998). Although red squirrels are primarily granivorous, they are also opportunistic generalists that exploit buds, fungi, shoots, cambium and phloem, nestling songbirds, young gray squirrels (*Sciurus carolinensis*), insect larvae, cottontails (*Sylvilagus floridanus*), beef, and bones (Yahner 2003).

Red squirrels usually are associated with the coniferous forests of Canada, the Rocky Mountains, and the northeastern United States (Figure 1). Optimal habitat includes mature stands of fir (*Abies* and *Pseudotsuga* spp.), spruce (*Picea* spp.), lodgepole pine (*Pinus contorta*), ponderosa pine (*P. ponderosa*), whitebark pine (*P. albicaulis*), and jack pine (*P. banksiana*) that provide ample seeds as forage and closed canopies as shelter and protection from predators (Smith 1968a; Smith 1968b; Rusch and Reeder 1978). Smith (1970) suggested that coevolution occurs between these squirrels and conifers. Seed predation by the squirrels exerts selective pressure on the trees, resulting in changes in

the reproductive characteristics of the conifers. The pines develop harder cones, which reciprocally selects for squirrels with stronger jaw musculature.

Squirrels inhabiting these coniferous forests have a tendency to larderhoard pine cones in the western part of their range and scatterhoard them in the eastern portion (Layne 1954; Smith 1968a; Kemp and Keith 1970; Rusch and Reeder 1978; Gurnell 1984; Hurly and Robertson 1990; Dempsey and Keppie 1993; Yahner 2003). Larderhoarded conifer cones are stored in a central food cache, or midden, within their territories (Yahner 2003). Red squirrels in western North America tend to be highly territorial, and aggressively defend their midden from conspecifics and other animals (Smith 1968a; Kemp and Keith 1970; Rusch and Reeder 1978; Gurnell 1984). The cones stored in middens are the primary food source for red squirrels during the winter, and territorial behavior occurs in order to secure an adequate year-round food supply (Smith 1968a).

At the southern extent of their geographic range, red squirrels inhabit deciduous forests or mixed deciduous-coniferous forests (Obbard 1987). These habitats, as well as pine plantations and fencerows, serve as suboptimal habitat, but squirrel populations can successfully occupy them as long as a sufficient food supply is present (Yahner 2003). Red squirrels in these regions generally do not display territorial behavior (Layne 1954; Dempsey and Keppie 1993).

In the fragmented, agricultural landscapes of the lower Midwest, red squirrels tend to occupy deciduous and mixed deciduous-coniferous woodlots. The animals occupy mixed stands and pine plantations throughout the northern portion of Ohio (M. Reynolds, Ohio DNR, pers. comm., unreferenced). In Indiana, they occupy deciduous

forests and pine plantations throughout the state, except those in the southwest (Goheen and Swihart 2003). The colonization of midwestern forests by this species is thought to be a recent event. In Indiana, the species was not recorded until approximately 60 years after European settlement (Mumford and Whitaker Jr. 1982). Goheen et al. (2003) suggested that red squirrels may be expanding their range through the Midwest; a process coinciding with high amounts of forest fragmentation caused by agriculture and development. These authors also contended that forest fragmentation has contributed to the decline of gray squirrels (*Sciurus carolinensis*) in the Midwest. The latter species appears to be more sensitive to fragmentation than red squirrels, so that the reduction in gray squirrels has facilitated the range expansion by red squirrels Goheen et al. (2003).

Although available red squirrel habitat in the lower Midwest may be suboptimal, few studies have addressed or quantified habitat use by red squirrels in this region. Research in Indiana suggested that the presence of red squirrels in deciduous woodlots is positively correlated with the presence of black walnuts (*Juglans nigra*), and the squirrels show a preference for forests containing this tree species (Goheen and Swihart 2005). Another study in Indiana found that the squirrels prefer deciduous woodlots with at least some conifers (Ivan and Swihart 2000). Goheen and Swihart (2005) also reported that red squirrels in Indiana did not show a preference for pine plantations. This is contrary to what one might expect, since the species is well-adapted to live in coniferous forests. However, it is important to note that pine plantations differ from natural forests in vegetative structure, primary production, and biodiversity. In addition, the home ranges of red squirrels occupying deciduous forests can overlap broadly (Layne 1954; Smith 1968a; Rusch and Reeder 1978). Evidence suggests that home range size is influenced

by habitat type, location, and calculation method, but generally ranges from 0.3-1.5 ha (Yahner 2003).

Red squirrels in Illinois

In the 1800's, red squirrels were present in northern Illinois, however the abundance and distribution of this species at that time remains unclear (Hoffmeister 1989). It is widely believed that red squirrels disappeared from the state in the late 1800's and probably remained absent until the 1970's, when reported sightings occurred in Kankakee and Iroquois counties (Hoffmeister 1989). A likely explanation for this apparent recolonization is that the Kankakee River provides a suitable habitat corridor for the species to immigrate into the state from Indiana. However, the origin of the current population remains speculative. Another possible explanation for the apparent reoccurrence of red squirrels in Illinois is that captive squirrels from Minnesota were imported and released in eastern Kankakee County. Although this explanation is often stated by residents in the area, there is no direct evidence of such a release. A third possibility is that the species was never completely extirpated from the state and a remnant population persisted in the Kankakee area (Hoffmeister 1989). The species is currently listed by the Illinois Department of Natural Resources (IDNR) as a "conservation priority mammal" due to its low numbers and restricted geographic range.

Prior to my study, the distribution of these squirrels was thought to be limited to a small area in the northeastern part of the state that includes Kankakee, Will, and Iroquois counties (Brown 1985; Neely and Heister 1987; Hoffmeister 1989; Figure 2). In this region, suitable habitat appeared to be restricted to pine plantations composed of red, white, jack, and/or Virginia pines (*Pinus resinosa, P. strobus, P. banksiana, and P.*

*virginiana*, respectively) and small tracts of deciduous or mixed forest embedded in a landscape matrix of corn and soybean fields. Twenty years ago, Wright (1985) initiated a study to quantify home range size, overlap, and territorial behavior by red squirrels in this region. However, sample sizes were small and few conclusions regarding habitat selection and home range size could be derived.

Since 2000, the IDNR has been actively girdling and removing non-native pines from public lands in northeastern Illinois. The potential effect of this program on the resident red squirrel population had not been addressed prior to my study, but there was concern that the removal of pines might eliminate the last vestiges of suitable habitat for red squirrels in the region. Therefore, I conducted this study to address two primary research objectives: (1) quantify home range size, habitat use and preferences of red squirrels in northeastern Illinois, and (2) estimate the current distribution of the species in Illinois. My purpose was to contribute to the conservation and management of this population by identifying critical habitat, comparing current and past geographic distributions to document whether the species' range is expanding, restricting, or stable in the state, and finally making recommendations regarding habitat management, particularly regarding pine removal.

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## FIGURES

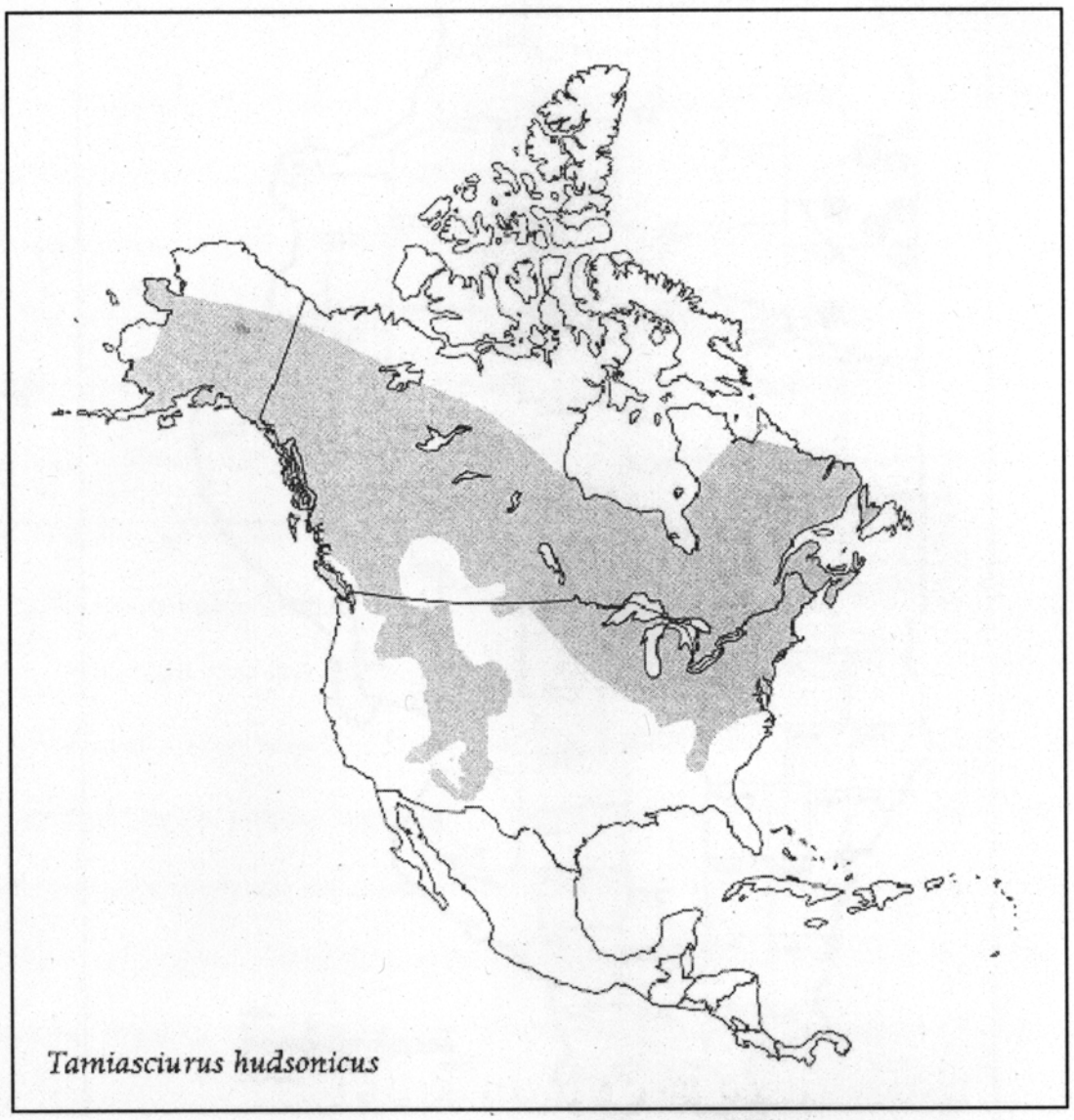


Figure 1. Geographic range of *Tamiasciurus hudsonicus* (Wilson and Ruff 1999).

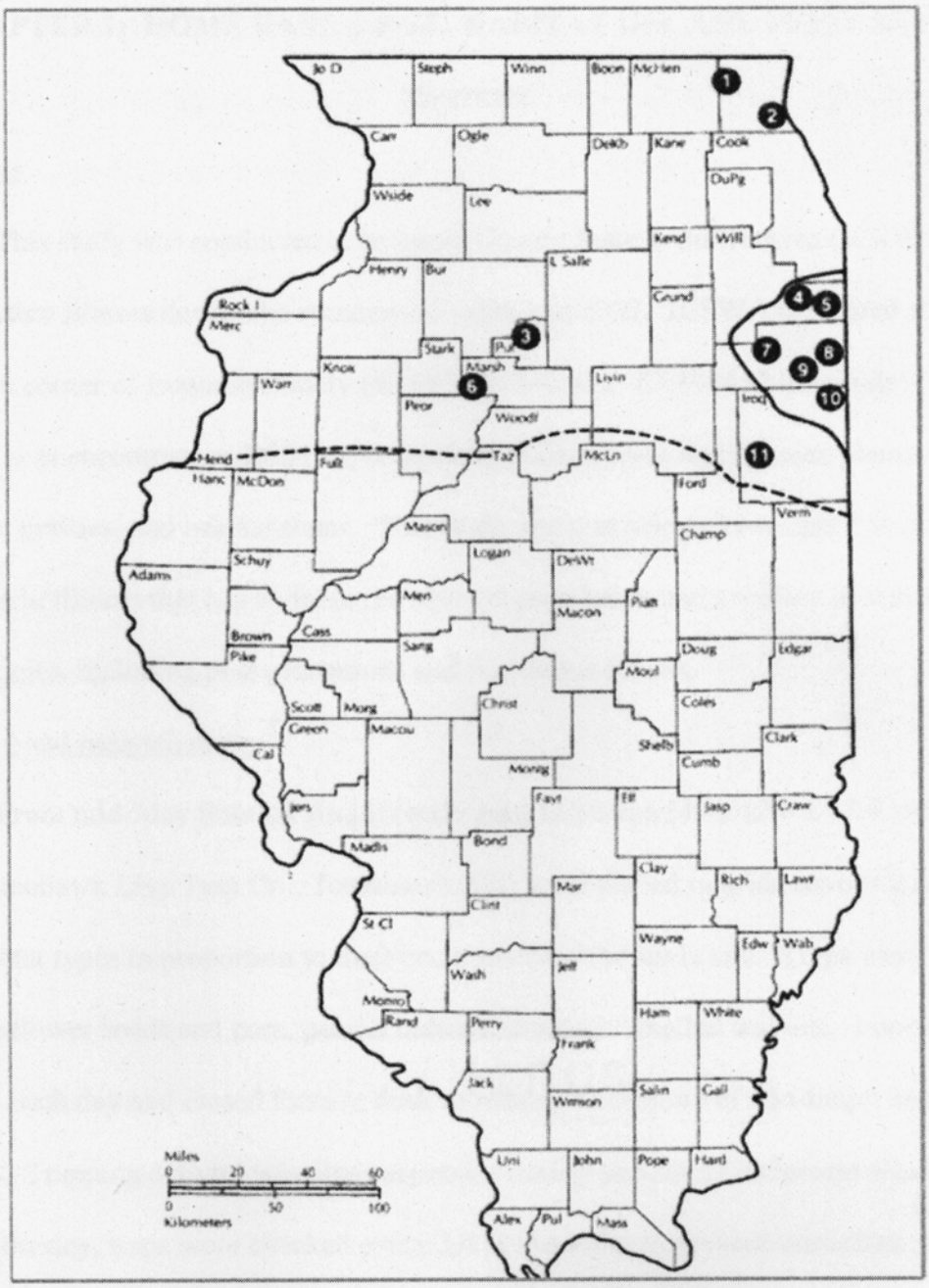


Figure 2. Range of red squirrels in Illinois prior to this study (Hoffmeister 1989). The historic range is the area north of the dotted line. The 1980's range is the area within the solid line. Numbered points indicate documented records of occurrence.

# CHAPTER 1: HOME RANGE SIZE, HABITAT USE AND PREFERENCES

## METHODS

### Study site

This study was conducted at Iroquois County State Wildlife Area (ICSWA) in northeastern Illinois during the summers of 2006 and 2007. ICSWA is located at the northeast corner of Iroquois County (40.993374 latitude, -87.598457 longitude) (Figure 1). The area encompasses 1,004 ha, comprised of deciduous forests, pine plantations, marshes, prairies, and oak savannas. This study site was selected because it is one of the few sites in Illinois that has a viable red squirrel population and a variety of suitable habitat types, including pine plantations and deciduous forests.

### Trapping and radiotelemetry

From mid-May through August each year, live traps (40 x 12.6 x 12.6 cm; model 603, Tomahawk Live Trap Co., Tomahawk, WI) were placed in grids covering each of five habitat types in proportion to their occurrence on the study site. Traps were baited with sunflower seeds and corn, peanut butter and oats, or shelled walnuts. I opened traps at dawn each day and closed them at dusk to reduce the capture of non-target nocturnal animals. Trapping activity was also suspended during periods of inclement weather. During the day, traps were checked every 3-4 hrs in order to prevent unnecessary trauma to captured animals. Trapped squirrels were transferred from the trap into a cloth handling cone (Koprowski 2002) where they were anesthetized with an intramuscular injection of 0.02 mg/gm ketamine plus 0.001 mg/gm xylazine (Kreeger et al. 2002). Once anesthetized, selected individuals were outfitted with a nylon-coated stainless steel radiocollar with a whip antenna (2.5-4 g; PD-2C, Holohil Systems Ltd., Ontario,

Canada). These collars weigh ≤ 2.3% of an adult red squirrel's body mass. Numbered ear tags (model 105-3; National Band and Tag Co., Newport, KY) were applied to the ear, body mass was measured with a spring scale (Pesola AG, Barr, Switzerland) accurate to 1 g, and total body length was measured with a metric tape measure.

Tissue samples were collected for genetic analyses with a 2 mm biopsy punch from the ear pinna, following the methods of Trizio et al. (2005). These samples were then stored in dessicant vials for subsequent DNA analysis in the laboratory at Eastern Illinois University. Trapping and handling protocols were approved by Eastern Illinois University's Animal Care and Use Committee under permit EIU06010 and followed guidelines set forth by the American Society of Mammalogists (Animal Care and Use Committee 1998).

Individual red squirrels were radiolocated throughout both summers, usually at least once daily. Squirrels were located by homing on the signal or triangulation at close range (~30 m) using a directional yagi antenna (Mech 1983). Homing was most common, allowing me to detect and record the animal's specific location, as well as the habitat type, dominant canopy trees, and understory vegetation at each location. When triangulation was necessary, 3-4 bearings were recorded at ~70-110° angles from 20-30 m away from the individual. Controlled tests conducted on transmitters placed in known locations resulted in a mean angular error of 2 m (SE = 0.3). Each location was identified using a GPS receiver (Garmin GPS III+, Olathe, KS) in UTM coordinates (NAD 83, Zone 16). I used ArcGIS (ver. 9.2) to overlay all radiolocations onto 2005 1.5-m resolution digital orthophoto quarter quadrangle (DOQ) aerial photographs (Illinois Natural Resources Geospatial Data Clearinghouse 2006) for analyses. I conducted

telemetry at different times throughout the day in order to capture the full range of each squirrel's daily movements.

It is typical for an animal's movements to be autocorrelated, as individuals rarely move in a completely random manner. In my study, I tried to reduce temporal autocorrelation by ensuring that the minimum time interval between successive radiolocations was 1-2 hrs. This interval was reasonable because it exceeds the time necessary for most squirrels to traverse their home range. It also increased the likelihood that radiolocations were biologically independent, thus reducing temporal autocorrelation between locations (Lair 1987). Several researchers have suggested that autocorrelated locations should be completely eliminated before home ranges are estimated (Swihart and Slade 1985; Worton 1987; Ackerman et al. 1990; Kenward 1992). While complete elimination facilitates the statistical significance, sample sizes are reduced, and biological significance may be diminished (deSolla et al. 1999). Furthermore, complete elimination of autocorrelation usually reduces statistical power and the accuracy of home range estimates, and can cause the potential loss of biologically important information (deSolla et al. 1999).

Home range estimation

Home ranges were calculated for individuals with ≥ 30 locations using Home Range Tools for ArcGIS (Rodgers et al. 2005) to optimize the accuracy of home range estimates (Seaman et al. 1999). One additional individual with 28 locations was included for this analysis in order to ensure thorough and conservative home range estimations. Two types of home ranges were calculated, the 90% fixed kernel "home range" and 50% fixed kernel "core area" (Figure 2). I elected to not calculate the minimum convex

polygon (MCP) home range due to its numerous well-known weaknesses (Jennrich and Turner 1969; Worton 1987; Harris et al. 1990; White and Garrott 1990). In addition, the MCP estimates are not useful for comparisons to previous research because of their sensitivity to sample size (Seaman et al. 1999). Alternatively, kernel estimators are less sensitive to sample size and provide a more accurate estimate of home range size. Kernel estimates are nonparametric probability density estimators of the utilization distribution. The use of kernel methods to estimate home ranges is increasingly favored over other parametric methods (Worton 1989). The 90% kernel is the "home range" estimate and considers areas that are usually used, excluding outlying locations which are rarely used. The 50% kernel "core area" identifies the areas of heaviest use, showing where the animals were located most often.

When using kernel estimates, it is important to select an appropriate smoothing parameter, or bandwidth (h). Several different automated methods exist for generating appropriate bandwidths including: (1) HREF, (2) least-squares cross-validation (LSCV), and (3) biased cross-validation (BCV). I decided against using HREF because of its tendency to over-smooth the utility distribution (Rodgers and Carr 1998). The method is effective when animals have unimodal utility distributions (Worton 1995), but many of the squirrels had multiple centers of activity within their home ranges. The BCV method differs from the LSCV method in that it finds an h-value in which the asymptotic mean integrated square error is minimized, rather than the mean integrated square error (Sain et al. 1994). Sain et al. (1994) showed that BCV can perform well in simulation studies, but when I tested the method with my data, utilization distributions tended to be over-smoothed. After further investigation, the bandwidth resulting from the LSCV method

(Silverman 1986) appeared to be most suitable for my data. Out of the three automated methods described above, the kernels derived from this method seemed to most accurately capture the animals' home ranges. Previous research also suggests that fixed kernel estimators with bandwidths chosen by the least-squares cross-validation method consistently produce more accurate home range estimates than other methods (Seaman et al. 1999).

Survival analysis

I used the MICROMORT program (Heisey and Fuller 1985) to calculate summer survival rates based on the sex and age of squirrels. This program is designed to estimate survival and mortality rates by using the number of radiodays and mortalities within a specified time interval. Program CONTRAST (Hines and Sauer 1989) was then used to compare survival rates between groups. This program compares survival rates by using a $X^2$ analysis for testing the null hypothesis that rates between groups are equal.

Habitat use

Based on the vegetation of the study site, 5 habitat types were identified: deciduous forest, pine plantation, brush savanna, grassland, and cropfield. Dominant tree genera within the deciduous category were oaks (*Quercus spp.)* and black cherry (*Prunus serotina)*. Pine plantations in the area were mostly composed of scotch pine (*Pinus sylvestris*); red and white pines were also present. The "brush savanna" category refers to a few small patches that were distinctive in composition with an open canopy containing very sparse amounts of pine and deciduous trees, and an extremely dense understory comprised mainly of blackberries (*Rubus* spp). Many downed trees and snags also were present in this habitat type. The grassland habitat type included marshes, wet and dry

prairies, and sand dune vegetation. Cropfields were composed of either corn or soybeans. These 5 habitat types were digitized on a 2005 DOQ basemap (0.5-m resolution) using ArcMap 9.2, (ESRI, Redlands, CA).

To investigate habitat use and preference, the entire 1,004-ha ICSWA and 751-ha of surrounding private land were classified as available habitat for radiocollared squirrels. I then overlayed each squirrel's individual radiolocations, core area contours, and home range contours on a DOQ basemap. Habitat use then was investigated at 2 spatial scales: (1) habitat selection at the scale of the home range (comparing habitat composition of home ranges to that of the study area), and (2) selection at the scale of the core area (comparing the composition of the core area to that of the home range). These scales are similar to Johnson's (1980) definition of 2$^{nd}$-order habitat selection (habitat composition within home ranges versus that of the geographic range) and 3$^{rd}$-order selection (composition of heavily used areas versus that of the home range), respectively.

Data analysis

Because various resource selection methods can yield different results and disagreement in the literature exists as to what method should be preferred (Alldredge and Ratti 1986; Alldredge and Ratti 1992; McClean et al. 1998; Manly et al. 2002), I found it necessary to evaluate the data with more than one method: (1) a chi-square analysis (Neu et al. 1974), and (2) compositional analysis (Aebischer et al. 1993).

Neu et al. (1974) introduced the use of a $X^2$ test to determine relative preference or avoidance of specific habitat types. The null hypothesis is that habitat types will be used in proportion to their availability. If the overall test is significant, individual preferred and avoided habitats can be evaluated with Bonferroni confidence intervals

around the proportions. Cherry (1996) suggested that Bailey confidence intervals (Bailey 1980) with a continuity correction should be used instead of the Bonferroni confidence intervals utilized in Neu et al. (1974). Therefore, I used 95% Bailey confidence intervals around the proportions for this analysis.

To determine how different habitat types ranked in relative preference, I also conducted a compositional analysis (Aebischer et al. 1993). This method uses MANOVA techniques to examine 2 data sets (used versus available habitats) which are expressed as proportions. I used Leban's resource selection software (1999) to investigate second- and third-order resource selection using both the $X^2$ test and compositional analysis. The compositional analysis was also performed in SAS (ver. 9.1) by using the program BYCOMP.SAS (Ott and Hovey 1997) to verify results.

Resource selection studies examine the ways that animals use their available habitat. Three sampling designs have been identified by Thomas and Taylor (1990): (1) population-level resource selection is assessed by examining availabilities and use for all resources for all animals; individuals are not recognized, (2) resource selection is assessed using individual animals and their habitat use is pooled across all individuals, and (3) habitat use and availability are assessed separately for each animal. I used designs 2 and 3 because resource selection is examined for individual animals, all data are typically used, and individual variation can be considered (Braun 2005).

In addition, ANOVA was used to determine if canopy cover varied between used and unused sites. Canopy cover was measured with a densiometer at red squirrel locations and at 110 randomly chosen wooded sites within the entire study area for comparison.

## RESULTS

Trapping, survival, and marking effects

In total, 103 red squirrels were captured, including 41 individual squirrels and 62 recaptures. I trapped a total of 3,660 trap-days in 2006 and 1,780 trap-days in 2007; therefore, the overall success rate was 52.8 trap-days per red squirrel captured. Three other sciurids inhabit the study area: gray squirrels, fox squirrels (*Sciurus niger*), and eastern chipmunks (*Tamias striatus*). During the 2 summers, I trapped only 1 gray squirrel and 8 fox squirrels, for a rate of 604.4 trap-days per tree squirrel captured. In contrast, eastern chipmunks (*Tamias striatus*) were very abundant on the study area and I caught 711 of these, resulting in a capture rate of 7.7 trap-days per chipmunk captured.

The physical condition of squirrels did not appear to be impacted by handling or the radiocollars. Three animals that were radiocollared in 2006 were recaptured in 2007. Two of these showed no evident ill-effects from wearing the collars for >12 months; the third was missing some hair under the collar apparently from wear, but no skin damage or infection had occurred. For all 3 individuals, the wound from the biopsy punch in the ear was completely healed, and none showed any signs of injury or infection around the metal ear tags. Similarly, squirrels recaptured within days or a few weeks of their initial capture showed no signs of physical impairment or infection associated with their radiocollars, ear tags, or biopsy punch marks. Red squirrels appeared to recover quickly from handling and invasive procedures.

Home range size, use of core areas, and survival analysis

Thirty-nine individuals (18 females, 21 males) were fitted with radiocollars and tracked to investigate their movements and habitat use. One female died after only 5

days, so she was eliminated from subsequent home range analyses. In addition, 3 males tracked in 2006 were recaptured, fitted with new collars, and tracked again in 2007. After analyzing their radiolocations for each summer, their home ranges were deemed to be independent between years and I treated each home range separately in subsequent calculations. Therefore, I calculated 41 home ranges and core areas for 38 individual squirrels based on 1,554 individual radiolocations, for a mean of 38 (SE = 0.79) locations per squirrel.

The mean home range size for these individuals was 1.7 ha (SE = 0.24). Core areas averaged 0.4 ha (SE = 0.06). Prior to testing for differences between groups (sexes, ages, and seasons), I conducted homogeneity of variance tests on home range and core area sizes for all groups. Results showed that 2-sample t-tests assuming equal variances were appropriate for these data. The t-tests revealed no differences in home range sizes between males (N = 24; $x$ =1.8 ha; SE = 0.38 ha) and females (N = 17; $x$ = 1.5; SE = 0.31 ha) ($T$ = -0.71, df = 39, $P$ = 0.48). In addition, no differences were found in the size of core areas used by males (N = 24; $x$ = 0.49, SE = 0.11 ha) versus females (N = 24; $x$ = 0.37, SE = 0.08 ha) ($T$ = -0.88, df = 39, $P$ = 0.38). Home range sizes also did not differ between adults (N = 32; $x$ = 1.8, SE = 0.41 ha) and juveniles (N = 9; $x$ = 1.2, SE = 0.24 ha) ($T$ = 1.07, df = 39, $P$ = 0.29). In addition, core area sizes between adults (N = 32; $x$ = 0.47, SE = 0.10) and juveniles (N = 9; $x$ = 0.35, SE = 0.07) did not differ ($T$ = 0.78, df = 39, $P$ = 0.44). Home ranges did not differ in size between 2006 (N = 24; $x$ = 1.8, SE = 0.36) and 2007 (N = 27; $x$ = 1.6, SE = 0.34) ($T$ = 0.36, df = 39, $P$ = 0.72). There was also no difference in the size of core areas between 2006 (N = 24; $x$ = 0.47, SE = 0.10) and 2007 (N = 17; $x$ = 0.39, SE = 0.09) ($T$ = 0.62, df = 39, $P$ = 0.54). Because home ranges

and core areas did not differ in size among sexes, ages or years, I pooled these data for the habitat use analyses. In addition, the home ranges and core areas of individual red squirrels overlapped with each other, possibly indicating an overall lack of territoriality during this season. Figure 1 illustrates overlapping core areas among individuals in 2006 and 2007.

Thirty-nine individuals were radio-tracked across both summers. For the survival analysis, the radiotelemetry time interval in 2006 was 18-May to 15-Oct; the interval in 2007 was 23-May to 10-Aug. The combined time interval for both summers was 231 days. Only 1 squirrel died over the course of the study, and this mortality was determined to be from predation. It is unknown what type of predator caused the mortality. Overall summer survival rate for all animals was 0.90 (SE = 0.09). Female survival rate averaged 0.78 (SE = 0.15) and male survival rate was 1.00 (SE = 0.00). No differences in survival rates were observed between sexes ($X^2 = 1.29$, $df = 1$, $P = 0.26$). Adult survival rate was 0.88 (SE = 0.10) and juveniles had a rate of 1.00 (SE = 0.00). Adult and juvenile survival rates also did not differ ($X^2 = 1.14$, $df = 1$, $P = 0.29$).

Habitat use

Results from the $X^2$ method show that the habitat composition of home ranges differed significantly from that of the study area, suggesting that 2nd-order habitat use is nonrandom ($G_{adj} = 7670$, $P < 0.0001$). Therefore, Bailey simultaneous 95% confidence intervals were calculated to investigate which habitat types were preferred and avoided. These results showed that grasslands and cropfields were avoided ($X^2 = 670$, $df = 4$, $P < 0.0001$ and $X^2 = 940$, $df = 4$, $P < 0.0001$, respectively; Table 1). In contrast, all 3 wooded habitats were preferentially selected (pines: $X^2 = 3238$, $df = 4$, $P < 0.0001$; deciduous

forest: $X^2 = 210$, $df = 4$, $P < 0.0001$; brush savanna: $X^2 = 42{,}296$, $df = 4$, $P < 0.0001$), as would be expected for a tree squirrel.

When I compared the habitat composition of core areas to that of the home ranges, it was evident that 3rd-order habitat selection also occured ($G_{adj} = 281$, $P < 0.0001$). As with 2nd-order selection, squirrels generally avoided grasslands ($X^2 = 80$, $df = 4$, $P < 0.0001$) and cropfields ($X^2 = 49$, $df = 4$, $P < 0.0001$) within their home ranges, instead positioning their core areas in pines ($X^2 = 16$, $df = 4$, $P < 0.05$) and brush savanna ($X^2 = 98$, $df = 4$, $P < 0.0001$; Table 2). However in contrast to the 2nd-order selection, my results further suggest that squirrels tended to avoid deciduous stands ($X^2 = 10$, $df = 4$, $P < 0.05$) within their home ranges if pines or brush savanna habitats were available.

I used compositional analysis to rank habitat types in terms of relative preference at both the 2nd- and 3rd-order levels of habitat selection (Tables 3 and 4, respectively). I rejected the null hypothesis that the composition of the red squirrels' home ranges was proportional to that of the study area (Wilk's $\lambda = 0.17$, $P < 0.0001$). Habitat types were ranked by preference as: (1) deciduous forest, (2) pines, (3) brush savanna, (4) grasslands, and (5) cropfields. Similarly, habitat types were not also used proportionally between core areas and home ranges (Wilk's $\lambda = 0.4786$, $P < 0.0001$). Habitat use in the core areas (3rd-order selection) showed that the order of preference is for brush savanna, followed by deciduous stands, pines, grasslands, and cropfields. Overall, the use of each habitat type relative to its availability at both the 2nd- and 3rd-order levels suggested that red squirrels preferred brush savanna, deciduous forest, and pine habitat types and avoided grasslands and cropfields (Figure 4). I found little evidence that red squirrels on

my study area preferred pine stands to deciduous stands; both habitat types were heavily used.

I performed compositional analysis in both SAS (ver. 9.1) and Leban's Resource Selection software (1999) in order to verify my results. The results of these 2 methods differed slightly in the lower rankings of habitat types. Because no major differences occurred and overall implications remained the same, I chose to focus on the results from the Resource Selection Software (Leban 1999) for simplicity.

At the outset of this study, I hypothesized that red squirrels would prefer forest patches with greater % canopy cover. I tested this hypothesis during the first summer by comparing canopy cover at sites where squirrels were radiolocated with randomly-selected sites. Canopy cover did not differ between occupied and random sites ($F = 2.41$, $df = 1$, $P = 0.121$).

## DISCUSSION

### Home range size, core overlap, and food caching

Summer home range size for all squirrels averaged 1.7 ha (SE = 0.24), and mean core area size was 0.4 ha (SE = 0.06). The size of both home ranges and core areas did not differ between males and females or adults and juveniles. Previous research has indicated that home range sizes of red squirrels vary across regions (Layne 1954; Smith 1968; Kemp and Keith 1970; Rusch and Reeder 1978; Gurnell 1984; Sullivan 1990; Vlasman and Fryxell 2002; Goheen and Swihart 2005). My home range estimates are within the size ranges reported in previous studies (Table 5). Home ranges can differ due to season, location, habitat type, and/or calculation method, but there is value in making comparisons despite this. For instance, evaluating home range sizes in different regions

and habitat types can provide insight into levels of habitat quality. A common assumption in wildlife biology is that the home range size of animals tends to be smaller in high quality, resource-rich habitat, and larger in lower quality, suboptimal habitat. The main reason for this is that animals need a home range large enough to meet their life requisites (food supply, nest sites, breeding ground, etc.), but no larger than necessary due to costs associated with travel and defense.

Forest composition in previous studies addressing home range size has been either coniferous, mixed coniferous-deciduous, or deciduous-dominated hardwoods. Obbard (1987) presents a review of territory and home range sizes of red squirrels across various habitat types. Based on this review and additional research, the size of red squirrel home ranges has shown a tendency to be larger in deciduous forests than in coniferous forests. Table 5 illustrates the size differential of red squirrel home ranges across various habitat types. These results may be indicative of lower habitat quality of deciduous forests when compared to the optimal habitat of coniferous forests. Due to the large home range sizes of red squirrels at ICSWA, it is possible that habitat quality is suboptimal in this region when compared to coniferous forests.

Across the red squirrel's North American geographic range, it has been difficult to simply characterize the species' territorial behavior and food-hoarding patterns (Hurly and Lourie 1997). Territoriality is widely thought to result from limited resources, and cone crops in coniferous forests can be limiting for red squirrels. In the boreal forests of western North America, individuals establish exclusive territories and prepare for the winter by larderhoarding pinecones in a central food cache (or midden) within their territories (Yahner 2003). Large quantities of cones can be stored there and individual

red squirrels aggressively defend their midden from conspecifics and other animals (Smith 1968; Kemp and Keith 1970; Rusch and Reeder 1978; Gurnell 1984). Years in which the cone production is low would cause food shortages, and the defense of middens may be critical to each animal's survival. Therefore, in these forests, year-round territorial behavior serves to protect a critical resource that may be only seasonally available (Smith 1968).

In contrast to the larder-hoarding habits in the western boreal forests, the red squirrels in the eastern boreal forests are usually territorial scatterhoarders, burying and hiding cones and nuts in separate locations throughout their home range (Hurly and Robertson 1990; Dempsey and Keppie 1993). Hurly and Lourie (1997) also observed some larderhoarding in this region.

In yet another region, red squirrels inhabiting the deciduous forests of eastern North America usually scatterhoard their food supplies and show no tendency to be territorial (Layne 1954; Dempsey and Keppie 1993). Unlike boreal forests, the deciduous and mixed forests of the eastern U. S. contain more diverse and dispersed food sources, reducing the benefits of territoriality, and explaining the lack of territoriality shown by the species in this portion of their geographic range.

An overall geographic trend is therefore observed with territorial behavior and food-hoarding habits of red squirrels. Generally, the animals are territorial larderhoarders in the coniferous forests of the West. In the boreal forests of the East, the squirrels continue to be territorial but usually scatterhoard their food instead of larderhoarding it. After transitioning south into the eastern deciduous forests, it is apparent that red squirrels are no longer territorial and continue to scatterhoard their food supply.

This regional pattern of behavior is consistent with my observations of red squirrels in northeastern Illinois, where core areas often overlapped and no evidence of larderhoarding was found. The home ranges and core areas of individuals overlapped on my study area suggesting that squirrels at ICSWA are not territorial in the traditional sense of inhabiting exclusive areas and excluding conspecifics. Aside from the occasional rattle vocalization, I saw no evidence of larderhoarding or other territorial behavior during my study. It was not unusual however to find piles of chewed walnuts beneath favorite foraging perches. Goheen (2002) observed an exception to this regional trend in Indiana where red squirrels occasionally constructed middens of black walnuts in deciduous woodlots.

In summary, current research suggests that red squirrels are territorial in boreal, coniferous forests, but rarely so in the deciduous and mixed forests of eastern North America. In the latter habitats, including those in northern Illinois, red squirrels exhibit overlapping home ranges and do not defend exclusive territories (Obbard 1987).

Survival

Overall summer survival rate for red squirrels was relatively high in my study, as only 1 mortality occurred out of 39 radio-collared individuals. This survival rate is much higher than the typical rates reported in the literature, with annual rates ranging between 0.31 (Steury and Murray 2003) and 0.33 (Kemp and Keith 1970; Halvorson and Engeman 1983). No differences in survival rates between sexes or ages occurred. This is also in contrast to typical findings from other studies in which females tend to have higher survivorship (Boutin and Larsen 1993; Halvorson and Engeman 1983), and juveniles also experience higher mortality (Halvorson and Engeman). My differing

results might be attributed to length of study season, as my research reflects summer survival, which may not reflect annual mortality rates. Survival rates can vary depending on food supply, with high survival occurring when food is plentiful and lower survival during poor food years (Gurnell 1987). In addition, during both field seasons, radiocollars were found on the ground with no signs of predation present. The most likely cause for this was that the collar attachment method used was not designed to be permanent. Therefore, my survival estimates are fairly conservative, with actual rates probably lower. Because so few mortalities from predation were observed in my study, it is difficult to determine what type of factors (predators, disease, etc.) play a major role in population regulation of this species. Additional research is needed to address this issue, and long term monitoring of this population would likely provide some valuable management implications regarding survival.

Habitat selection and preferences

The home ranges of red squirrels on ICSWA were comprised predominantly of the forests, suggesting that within the study area, squirrels select deciduous and pine habitats. In turn, grasslands and agricultural fields (predominantly corn) were avoided. These patterns are to be expected, as red squirrels are forest-dwelling animals. However, at the finer scale of habitat preferences within the home range, the 2 methods of quantifying habitat preferences produced somewhat different results. Specifically, the $X^2$ method suggested that red squirrels preferred pine and brush savanna habitat types, and used deciduous forest and other habitat types less often. These 2 preferred habitat types contained pine trees, suggesting that these red squirrels use pines preferentially when they are present within a home range. When I analyzed habitat use at the same scale with

compositional analysis, the results suggested that brush savanna was preferred to pines. Here the relative rankings were brush savanna > deciduous > pine.

At the study site scale, red squirrels used deciduous forest more than any other habitat type. This result was somewhat surprising because red squirrels are associated with conifers over much of their geographic range, and strong evidence suggests that red squirrels are well-adapted to and coevolved with conifers (Smith 1970). Therefore, I hypothesized that the ICSWA population would show a preference for the pine plantations present on my study area. Using compositional analysis, my results indicate otherwise. Although pine plantations were used, they were not preferred over the other forested categories at either scale of selection. Goheen and Swihart (Smith 1970) also reported that red squirrels showed no particular preference towards conifers, and readily used deciduous forests at the southern extent of their range in northern Indiana.

Although I did not quantify the relationship, an important component of deciduous woodlots occupied by red squirrels appeared to be the presence of mature walnut (*Juglans niger*) trees. Much of ICSWA was composed of deciduous forest without walnuts, and red squirrels were only rarely found in these areas. In addition, I often found the chewed remains of walnuts below favorite feeding perches used by these squirrels, and core areas often contained mature, mast-bearing trees. Red squirrels were often observed transporting and eating walnuts, and it is evident that they provide an important food source. Of the animals I tracked, 7 had core areas comprised entirely of deciduous forest and each contained mature walnut trees. Goheen and Swihart (2005) found that walnuts were important to red squirrels in Indiana. These nuts may be of particular importance because their heavy shells reduce their perishability compared with

other food items (Goheen et al. 2003; Goheen and Swihart 2005). Based on their research and mine, I speculate that the presence and abundance of red squirrels in Illinois' deciduous forests are positively related to the presence and abundance of mature walnut trees.

Compositional analysis ranked brush savanna as the most highly preferred habitat type within core areas, ranking it as significantly preferred over pines, but not over deciduous forests. The $X^2$ method also showed a relative preference for brush savannas. Even though this habitat type was scarce on my study area, it was an important component of home ranges when present. I suspect this habitat was important because it provided very thick blackberries and ground cover that the squirrels used when traveling and foraging on the ground. The large extent of time that squirrels spent on the ground was unexpected. The thick protective ground cover would provide shelter from most avian and some terrestrial predators when the squirrels foraged in these areas. In addition, the many fallen trees and snags found in this habitat type may provide ground-level food caches and nest sites. Brush savannas contained both pine and deciduous trees, so I cannot determine whether the heavy use of this category was related to the particular preference for one taxa or the other. Rather, it appeared likely that it was the composition or structure of the understory and groundcover strata (e.g., the presence of thick underbrush, snags, and downed wood) that influenced the squirrel's preference for this habitat type.

Since red squirrels preferred the brush savanna, future management plans should include the provision of this habitat type. My data and field observations suggest that its key components are likely thick underbrush, snags, downed wood, and mast-producing

pines and/or walnuts. These components would provide the squirrels with protection from predation, nesting sites, additional food-hoarding sites, and sources of food. Silvicultural practices that include the thinning of canopy trees to stimulate the growth of woody understory, retention of walnuts and mast-producing species, and periodic prescribed burns and/or brushhogging to retard the development of midstory trees, would produce these features. During the summer season, the red squirrels appeared to spend considerable time in this habitat type.

Although pine plantations were not heavily preferred over other forest types on my study area, I cannot dismiss the importance of conifers as a resource to red squirrels. The brush savanna preferred by squirrels contained sparse, mature pine trees as did the pine plantations inhabited by some individuals. Two previous studies in Indiana indicated a positive relationship between red squirrels and conifers in that state and the authors speculated that conifers are important to the survival of these animals in the Midwest (Nupp 1997; Goheen and Swihart 2005). In addition, even though the compositional analysis did not show a preference for pine plantations within home ranges, based on the $X^2$ results and my own field observations, I believe that pines were an important component of core areas when present within the home range.

The home range of every radiocollared red squirrel contained some forest with dense understory and squirrels were rarely sighted on the ground where this was sparse. The most apparent function of dense understory is to provide the squirrels with protection from predation. Although I did not quantify the importance of a dense understory to Illinois' red squirrels, 2 seasons of radiotracking and behavioral observations lead me to believe that its presence contributes to the local persistence of this species.

Towards the end of my study, the IDNR had begun to girdle mature pine trees and remove plantations on the ICSWA because these trees are not native to the region. Concerns have been expressed that pine removal may reduce the distribution, abundance, and persistence of red squirrels on ICSWA and other public lands. However, based on my results, it seems likely that red squirrels should be able to persist on the site, as long as deciduous woodlots are maintained with a walnut component; particularly if forest patches are interconnected with wooded corridors containing thick understories. Management to maintain or increase other habitat features likely to benefit these squirrels should also be considered. For example, maintaining mast-producing trees such as oaks and hickories (*Carya* spp.), cavity trees, snags, logs, and downed wood would likely improve habitat quality. My study was not designed to assess habitat needs in the winter, but these features should provide winter food and protective shelter as well.

Presence and interactions with other Sciurids

Extensive and intensive live-trapping at ICSWA showed that low numbers of gray and fox squirrels were present and sympatric with red squirrels on the site. However, generally where red squirrels were abundant, very few gray and fox squirrels were present. Although it cannot be proven in this study, I suspect that local habitat characteristics alter the competitive balance among these 3 species of tree squirrels. I did not witness direct interactions between any 2 species, so cannot speculate as to whether interference competition, exploitative competition, or both may influence the distribution and relative abundance of these species. In contrast, chipmunks were very abundant in local areas occupied by red squirrels. I was also impressed by how frequently red squirrels were found traveling or foraging on the ground. In this way, the behavior of red

squirrels resembled that of chipmunks; and it would appear that the latter species could be important food competitors with red squirrels in this area during the summer. Both species are diurnal and primarily granivorous animals with considerable overlap in their diet. This competition would be eliminated in the winter when chipmunks hibernate, while red squirrels stay active.

In conclusion, I found that red squirrels readily use deciduous forests in northeastern Illinois and that the brush savanna habitat type is used heavily within home ranges when available. Furthermore, my data suggest that mature walnut trees and a dense understory are important habitat components for these animals. Gray and fox squirrels were not abundant in forests used by red squirrels, but chipmunks and red squirrels appear to be competing for food in these habitats during the summer months. My results further suggest that red squirrels are likely to persist at ICSWA in spite of the ongoing removal of pine trees. This is because they were not dependent on pines and were frequently found in forests lacking a pine component, provided that mast-producing walnuts and dense understory vegetation were present. Finally, I found little evidence of territorial behavior in this population; home ranges and core areas frequently overlapped and middens of pinecones or walnuts were not observed. These squirrels appear to be non-territorial scatterhoarders.

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Table 1. Habitat composition of the Iroquois County study site (habitat available) versus that within the home ranges (habitat use) during the summers of 2006 and 2007.

| Habitat type | Study site composition (ha) | Proportion of study area | Observed composition of home ranges (ha) | Observed proportion of home ranges | Expected composition of home ranges (ha) | 95% Bailey confidence intervals on observed home range proportions |
|---|---|---|---|---|---|---|
| Pine plantation | 70 | 0.04 | 13.6 | 0.218 | 2.8 | $0.201 \leq p_1 \leq 0.235$ |
| Deciduous | 775 | 0.44 | 41.3 | 0.592 | 30.3 | $0.572 \leq p_2 \leq 0.612$ |
| Grassland | 421 | 0.24 | 4.7 | 0.042 | 16.5 | $0.034 \leq p_3 \leq 0.051$ |
| Cropfield | 486 | 0.28 | 2.5 | 0.025 | 19.3 | $0.019 \leq p_4 \leq 0.032$ |
| Brush savanna | 3 | < 0.01 | 6.9 | 0.123 | < 0.1 | $0.110 \leq p_5 \leq 0.137$ |
| Total | 1755 | | 68.9 | | 68.9 | |

Table 2. Habitat composition of the home ranges (habitat available) versus that within the core areas (habitat use) during the summers of 2006 and 2007.

| Habitat type | Home range composition (ha) | Proportion of home ranges | Observed composition of core areas (ha) | Observed proportion of core areas | Expected composition of core areas (ha) | 95% Bailey confidence intervals on observed core area proportions |
|---|---|---|---|---|---|---|
| Pine plantation | 13.6 | 0.197 | 4.3 | 0.247 | 3.5 | $0.230 \leq p_1 \leq 0.265$ |
| Deciduous | 41.3 | 0.599 | 10.2 | 0.554 | 10.8 | $0.534 \leq p_2 \leq 0.574$ |
| Grassland | 4.7 | 0.068 | 0.4 | 0.013 | 1.2 | $0.009 \leq p_3 \leq 0.019$ |
| Cropfield | 2.5 | 0.036 | 0.2 | 0.008 | 0.6 | $0.005 \leq p_4 \leq 0.012$ |
| Brush savanna | 6.9 | 0.100 | 2.9 | 0.178 | 1.8 | $0.163 \leq p_5 \leq 0.194$ |
| Total | 68.9 | | 18.0 | | 18.0 | |

Table 3. Results of compositional analysis showing the relative preferences of red squirrels for each habitat type relative to the others at the 2nd-order level of habitat selection (study site composition versus home range composition). *T*-statistics and their corresponding *P*-values are given. Probabilities $\leq 0.05$ suggest that the habitat type listed in the first column is significantly preferred over those listed in the other columns.

| Rank | Deciduous | Pine plantation | Brush savanna | Grassland | Cropfield |
|---|---|---|---|---|---|
| #1 Deciduous | - | 2.89<br>0.006 | 4.06<br>< 0.001 | 6.76<br>< 0.001 | 9.55<br>< 0.001 |
| #2 Pine plantation | | - | 0.97<br>0.337 | 1.96<br>0.057 | 4.16<br>< 0.001 |
| #3 Brush savanna | | | - | 1.89<br>0.067 | 2.80<br>0.008 |
| #4 Grassland | | | | - | 1.85<br>0.071 |

Table 4. Results of compositional analysis showing the relative preferences of red squirrels for each habitat type relative to the others at the 3rd-order level of habitat selection (home range composition versus core area composition). *T*-statistics and their corresponding *P*-values are given. Probabilities $\leq 0.05$ suggest that the habitat type listed in the first column is significantly preferred over those listed in the other columns.

| Rank | Brush savanna | Deciduous | Pine plantation | Grassland | Cropfield |
|---|---|---|---|---|---|
| #1 Brush savanna | - | 1.77<br>0.083 | 2.04<br>0.048 | 4.29<br>< 0.001 | 4.35<br>< 0.001 |
| #2 Deciduous | | - | 0.51<br>0.610 | 2.60<br>0.013 | 2.15<br>0.038 |
| #3 Pine plantation | | | - | 1.76<br>0.086 | 1.86<br>0.070 |
| #4 Grassland | | | | - | 0.095<br>0.925 |

Table 5. Territory/home range sizes of red squirrels in various forest types.

| Forest Type | Location | Average territory/home range size (ha) | Season | Method | Source |
|---|---|---|---|---|---|
| Coniferous | British Columbia, Canada | 0.79 | Apr.-Sept. | Observations | Smith 1968 |
| Coniferous | Alberta, Canada | 0.24-0.66 | Year-round | Observations | Rusch & Reeder 1978 |
| Coniferous | Colorado | 0.56 | Sept.-Nov. | Observations | Gurnell 1984 |
| Coniferous | British Columbia, Canada | 0.63 | Year-round | MCP | Sullivan 1990 |
| Coniferous | Ontario, Canada | 0.79 | May-July | MCP | Vlasman & Fryxell 2002 |
| Mixed | Alberta, Canada | 0.4-0.8 | June-Aug. | Observations | Kemp & Keith 1970 |
| Deciduous dominant | New York | 1.1-2.44 | June-Aug. | Observations | Layne 1954 |
| Deciduous dominant | Indiana | 0.88-1.03 | Year-round | 90% kernel | Goheen & Swihart 2005 |
| Deciduous dominant | Illinois | 1.7 | May-Aug. | 90% kernel | Hanson 2007 |

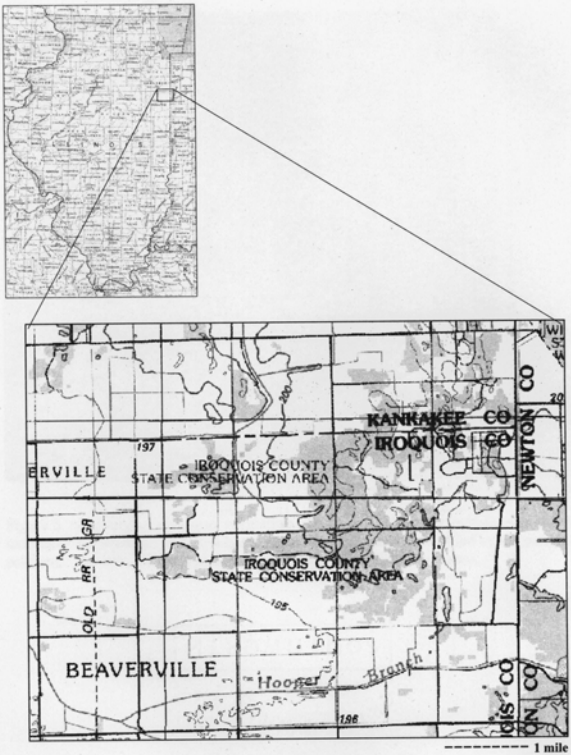


Figure 1. Map of Iroquois County State Wildlife Area in northeastern Illinois; located one mile from the Indiana border (Illinois Geospatial Clearinghouse 2007).

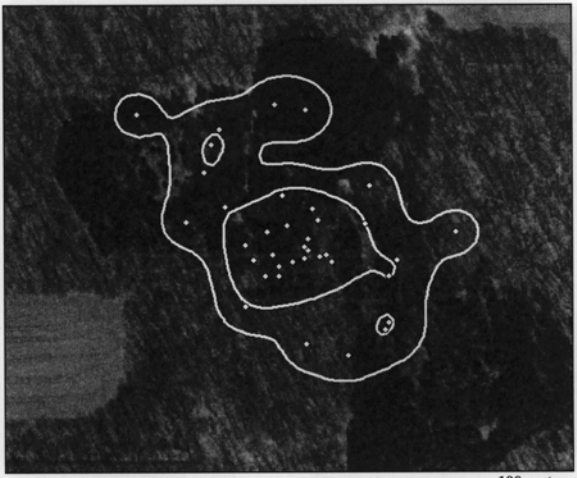


Figure 2. An example of a kernel estimation. The dots represent the radiolocations of an individual red squirrel. The 90% home range is the region encompassed by the outer polygon. The 50% core area is the area outlined by the 3 inner polygons.

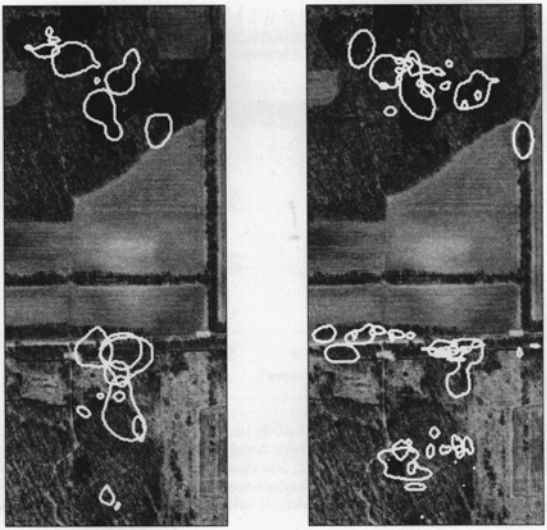

Figure 3. Images showing overlap among core areas on DOQs. The left image is from the 2006 field season; the image on the right is from 2007.

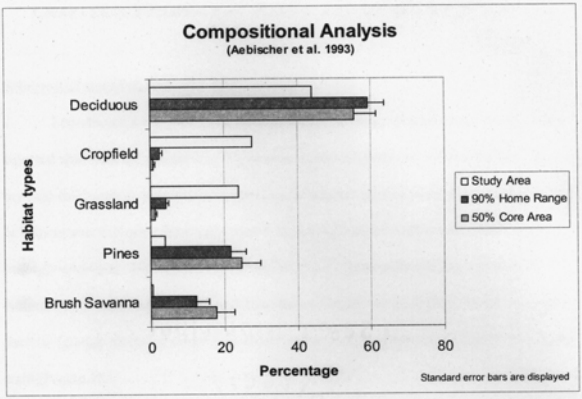


Figure 4. Habitat composition analysis of the study area, home ranges, and core areas used by red squirrels at ICSWA. Second-order habitat selection can be ascertained by comparing the composition of the study area (habitat available) to the composition of the home ranges (habitat used). Third-order selection can be observed by comparing the composition of the home range (habitat available) to that of the core area (habitat used).

# CHAPTER 2: THE DISTRIBUTION OF RED SQUIRRELS IN ILLINOIS

## METHODS

Selection of woodlots to be surveyed

I conducted audio playback surveys to determine the presence of red squirrels at selected woodlots in northeastern Illinois during the summers of 2006 and 2007. Prior to my first field season, information regarding the known geographic range of red squirrels in Illinois was collected from published records and maps (Hoffmeister 1989) and through interviews with state and regional field biologists at the IDNR, the Illinois Natural History Survey (INHS), and The Nature Conservancy (TNC). These data were used to develop an initial range map showing the species approximate distribution in the state (Figure 1).

I subsequently focused playback surveys on forests on public lands because time and resources were too limited to survey private parcels extensively. However, when time allowed, additional private lands were surveyed with permission from the landowners. Forests and woodlots were surveyed in Kankakee, Iroquois, Will, LaSalle, Grundy, Vermilion, and Ogle counties. Potential habitats within the known geographic range of the species were surveyed first, followed by areas with apparent suitable habitat at the edges of the range. When squirrels were detected at the edge of the known range, surveys were conducted just beyond this new perimeter in expanding arcs. In turn, when squirrels were not detected at a site, the next habitat patch surveyed was one located closer to the last known woodlot containing the animals' presence. By using this approach, the distribution of the red squirrels was systematically investigated in all directions.

Since the geographic range of red squirrels in Illinois extends west from the Illinois/Indiana border, I hypothesized that the species was emigrating northwest from Indiana, particularly along the Kankakee River corridor. Therefore, I concentrated many surveys in this region. The landscape south and southwest of the known range is dominated by row crops and the woodlots here are scarce, small, and isolated. Little public land exists in this area, so the surveys that were conducted here were mostly on private land. In contrast, the landscape north of the known range is more urban, encompassing the southern Chicago suburbs. Forest and woodlots here are also fragmented, heavily used for recreation, and surrounded by areas of abundant human activity. To the west, the Kankakee River is bordered by the city of Kankakee. More public land occurs west of the city including Kankakee River State Park (KRSP), the Des Plaines Fish and Wildlife Area (DPFW), Goose Lake Prairie State Natural Area (GLP), and the Chicago-area Forest Preserves.

Conducting Playback surveys

The forests and woodlots constituting potential red squirrel habitat were identified first on digital orthophoto quarter quadrangle (DOQ) aerial photographs using ArcGIS 9.2 (ESRI, Redlands, CA). I used these digitized maps to establish transects parallel to the long axis of each forest patch. Transects were situated 150 m apart, running parallel to each other. Transects were then surveyed using a Global Positioning System (GPS) receiver and compass. Playback stations were situated at 75-m intervals along each transect and the first and last stations were located ~30 m inside the woodlot edge. I made every effort to ensure complete coverage of the length and breadth of each site.

At each station, the researcher played an audio cassette recording of a red squirrel rattle call (Cornell Ornithology Laboratory, Ithaca, NY) that approximated the volume of a natural call. The call was played for 10-20 s, followed by a 30-s period of listening and watching for squirrel responses. This process was repeated 3 times at each station. Once all stations on all transects had been surveyed, I recorded whether the red squirrels were present or apparently absent at each site. Their presence was confirmed only when individuals were seen or heard; however, observations of red squirrel sign (middens or distinctive chew patterns on hard mast) were also recorded. When a squirrel was detected, its location was recorded in UTM coordinates (Zone 16, NAD 83) and any vocalizations and activities of the squirrel were recorded. At these confirmed locations, I recorded the general vegetative composition and structure, including: forest type (deciduous, coniferous, mixed), dominant canopy tree species, relative abundance of shrubs and ground cover, and the presence or absence of walnuts (*Juglans* spp.), pines (*Pinus* spp.), hard mast, and other tree squirrels (*Sciurus niger* and *S. carolinensis*).

Because red squirrels are diurnal and avoid periods of most intense heat in the middle of the day during summer (Obbard 1987), I conducted surveys during the 4-hr periods after sunrise and before sunset during the summers of 2006 and 2007. Additional surveys were conducted during the fall of 2006 and winter of 2006-07. Surveys were not conducted when winds exceeded 20 mph or rain was occurring.

Playback surveys were completed at 40 sites in 7 counties in northeastern Illinois. Eighteen sites were visited in 2006 and 22 additional sites were surveyed in 2007. All of the surveyed woodlots except for White Pines Forest State Park were predominantly dominated by deciduous hardwoods, particularly oaks (*Quercus* spp.) and hickories

(*Carya* spp.). Most of the surveys (38 out of 40) took place in the summer. Three additional surveys took place by canoe at the following sites: the Kankakee River through Momence Wetlands (Kankakee Co.), the Vermilion River through Middle Fork State Fish and Wildlife Area (Vermilion Co.), and the Vermilion River through Kickapoo State Park (Vermilion Co.). In these surveys, the rattle call was played 3 times at stations placed at intervals of 200-800m river distance. Stations were alternated at opposite sides of the river banks during surveys.

Additional sources of information on red squirrel distribution

Additional information on the distribution of red squirrels in Illinois was obtained through phone interviews, posted public notices, and newspaper/newsletter articles. Wildlife biologists throughout northern Illinois provided specific locations of squirrel sightings as well as the approximate date that squirrels were known to inhabit certain areas. These biologists also provided the names and contact information of additional reliable observers and landowners. I developed and placed posters with color photographs of red squirrels and my contact information at parks and wildlife preserves encouraging the public to contact me if they had information on red squirrel sightings. Finally, the Kankakee Daily Journal, Illinois Audubon Society, and The Nature Conservancy printed articles about the study with photographs of red squirrels requesting that readers contact me if they saw or knew of red squirrels in the region.

## RESULTS

Telephone and email surveys

I contacted 18 biologists and talked with many knowledgeable amateurs during this 2-year study. These interviews resulted in 11 new locations for the species, all

provided by wildlife professionals in the region. Of these 11, 6 were subsequently confirmed during playback surveys. In addition, one biologist reported that red squirrels were present in Thorn Creek Woods Nature Preserve (near Chicago Heights) in the late 1970's but are now apparently absent. I conducted several surveys in the preserve during the summer of 2007 and found no evidence of red squirrels.

Playback surveys

Red squirrels were detected at 11 of 40 sites surveyed, a detection rate of 27.5% (Table 1). The 3 surveys by canoe resulted in no sightings of red squirrels. In each of the 11 sites where red squirrels were detected, the squirrels' response to the recorded call was heard first, and then the animal was observed. At only 1 site, a woodlot near Watseka, did I find sign of red squirrels but could not confirm their presence with playback calls. The sign here was old discarded walnut shells with chew patterns resembling those of red squirrels. Based on the age of the material, it appeared that the site had once been occupied, but was not occupied at the time of the survey. I conclude that playback surveys greatly enhanced the likelihood of detecting squirrels in northern Illinois.

Seven of the 11 woodlots occupied by red squirrels were within 2 km of the Kankakee or Iroquois Rivers. Another site, the Del Rey Department of Transportation site (DOT), was within 1 km of Spring Creek, an Iroquois River tributary. Two occupied sites (Savickis private property and Iroquois County State Wildlife Area) were within 10 km of Willow Slough Fish and Wildlife Area in Indiana (WSFWA). The final site where red squirrels were found was at GLP. The woodlot here is small, isolated, surrounded by more than 1,000 ha of prairie and > 1.5 km from the nearest woodlot or forested riparian corridor.

Of the 20 surveyed forests and woodlots that were located within 2 km of either the Kankakee, Iroquois, Des Plaines, or Illinois rivers, 7 (35%) were occupied by red squirrels. In contrast, only 4 of 20 (20%) surveyed woodlots that were > 2 km from river corridors were occupied. The latter group consisted of more isolated woodlots, surrounded by corn and soybean fields. Therefore, I suspect that contiguous stretches of riparian forest along these rivers provide primary habitat and movement corridors for the species.

Red squirrels were detected in deciduous hardwood forests, both with and without the presence of conifers. The understory in these forests varied from sparse to very dense. Two common factors emerged for all occupied woodlots: (1) the presence of mature walnut trees, and (2) gray squirrels were scarce or apparently absent.

Patch size varied among woodlots, from 5.4 ha to > 1,500 ha. In addition, the shape of woodlots occupied by red squirrels varied widely from narrow, linear patches to wide, contiguous forests. I found no evidence that the size or shape of patches influenced occupancy. Several woodlots that were < 24 ha in size were occupied, suggesting that this species is not particularly area sensitive. In addition, although most occupied patches were < 2 km from forested riparian corridors, several were > 2 km from the nearest apparent habitat. This suggests that these squirrels are capable of dispersing across relatively long stretches of unsuitable habitat. For example, squirrels were found on both sides of the major rivers in this region, on both sides of Interstates 57 and 55, east and west of Kankakee and its suburbs, and in at least one woodlot surrounded by 1,000 ha of restored prairie.

The results from playback surveys and personal interviews allowed me to construct a current geographic range map of for red squirrels in Illinois (Figure 2). These results suggest that the species is still limited to a portion of northeastern Illinois, south of Chicago, but their geographic range is broader than previously known. My results extend the species' range by ~48 km to the southwest and ~32 km to the northwest. In addition, the northern extent of the range now appears to be 25 km further south than was previously reported. Whether the latter range contraction is related to urban sprawl in the southern Chicago suburbs is not known, but appears likely.

In summary, my research suggests that red squirrels occupy both isolated and riparian deciduous forests, and mixed pine-deciduous plantations across a somewhat broader area of northeastern Illinois than previously known. I cannot say whether this apparent range expansion is due to successful emigration by the squirrels or more effective and extensive surveys than have previously been conducted.

## DISCUSSION

The use of playback surveys resulted in the sightings of red squirrels at 11 different sites across northeastern Illinois. The detection of red squirrels at 3 of these sites (DPFW, GLP, and DOT woodlots) illustrates how the outer perimeter of the geographic range has apparently expanded to the northwest and southwest. The presence of red squirrels at these locations had not been documented prior to this study.

Telephone and email surveys of wildlife biologists provided additional useful information regarding new sites occupied by squirrels, as well as an approximate timeframe for occupation at several sites. Although many of these reports were for sites within the previously-known geographic range, 3 reports extended the known range to

include: GLP, a woodlot near Clifton High School (CHS) in Iroquois County, and a woodlot in Custer Park (CP) located near Wilmington in Will County. The report of squirrels at GLP resulted in a subsequent playback survey at that site that confirmed red squirrel presence. The reports for CHS and CP were beyond the perimeter of the previously-known range and eventually served to fill spatial gaps between more distant occupied sites and occupied sites closer to the central portion of the range.

These new locations, and temporal information provided by local biologists, suggest that red squirrels have probably expanded the size of their range in Illinois during the past 30 years, primarily to the west. In turn, there may have been some contraction at the northern extent of the range, just south of Chicago Heights and the southern suburbs. Two possibilities for the range expansion are that: (1) the squirrels were present at these locations, but went unnoticed for the past 30 years, or (2) red squirrels have expanded their range during this period, primarily using the Kankakee and Iroquois River corridors as dispersal routes. The first explanation seems unlikely because both the GLP and DPFW sites are heavily managed and frequently visited by outdoor enthusiasts. Therefore, if red squirrels were present, they likely would have been detected, reported, and documented.

I hypothesize that red squirrels are emigrating in a northwest direction along the Kankakee River corridor from Indiana and southwest along the Iroquois River corridor and its tributaries (Figure 2). Forests along these streams provide suitable habitat and may facilitate movement and range expansion. Goheen et al. (2003) suggested that red squirrels were expanding their range in the lower Midwest and my data support this premise.

My results also suggest that some range contraction may have occurred south of the Chicago Metropolitan area. For example, red squirrels were present at Thorn Creek Woods Nature Preserve (TCW) in the late 1970's, but playback surveys and field observations at that site and surrounding suitable habitat produced no evidence of squirrels. Obviously, a number of factors could lead squirrels to depart or become locally extinct in this area, but increased urban development and roadways may contribute to this range contraction.

Although squirrels were found predominantly in forests and woodlots on or near river corridors, the animals also were found in small, isolated woodlots surrounded by grasslands and agricultural fields. The GLP site was the most notable example of this. A red squirrel was detected in a small (~5 ha), deciduous woodlot that is surrounded by restored prairie and actively managed with prescribed burns. Perceived predation risk and energetic costs tend to be higher in risky habitats such as forest clear-cuts (Bakker and Van Vuren 2004). In Illinois, grasslands and cropfields would appear to be risky habitats for red squirrels. My results suggest that these habitats are not insurmountable barriers to the movement of red squirrels, consistent with previous assertions that red squirrels are relatively insensitive to the isolation of woodlots (Nupp and Swihart 2000; Goheen et al. 2003).

I successfully detected red squirrels in 11 of 40 surveyed forests across northeastern Illinois; however, I was unable to prove definitively that squirrels were absent from the other 29 surveyed. An important apparent trend that emerged during the playback surveys was that gray squirrels were much more common in woodlots lacking red squirrels than in those occupied by red squirrels. I cannot say whether this represents

the effects of competition between the 2 species, differences in habitat preferences, or other factors. However, gray and red squirrels share many resources and a high degree of interspecific competition can occur between them (Nupp and Swihart 2001). My observations are consistent Goheen et al.'s (2003) notion that the persistence of red squirrels in Midwestern deciduous woodlots may be facilitated by a decline in gray squirrel abundance due to habitat fragmentation. Based on the playback survey data, I speculate that in the deciduous woodlots where red and gray squirrels are sympatric, the abundance of gray squirrels and red squirrels are inversely correlated. Although my research was not designed to test this hypothesis, this merits future research.

During playback surveys, all detected red squirrels vocalized in response to the audio-recordings. Red squirrels have 5 different calls: the rattle, screech, chirp, buzz, and growl (Smith 1968; Smith 1978; Lair 1990; Greene and Meagher 1998). Each serves a particular purpose and facilitates particular behavioral responses from conspecifics and other animals. The rattle, screech, buzz, and growl calls are associated with territorial and aggressive behavior aimed at conspecifics. In contrast, the chirp is as an alarm call used in the presence of potential predatory threats (Greene and Meagher 1998). I used the rattle call during playback surveys and most individuals responded by rattling back. Therefore, red squirrels in Illinois do respond to this territorial call, even though the species does not appear to exhibit territorial behavior. The rattle call may have a more general purpose in this region, possibly notifying other squirrels of the caller's presence.

Future studies should consider conducting playback surveys during the winter season. The thick canopy cover of deciduous woodlots during the summer can obstruct

vision, making it more difficult to observe or detect red squirrels. Viewing the animals would likely be easier in the winter, when the trees have shed their leaves.

In conclusion, I defined the current geographic range of red squirrels in northern Illinois. Presence/absence of the squirrels was successfully surveyed in individual forests throughout the region using a combination of playback surveys in the field and telephone and email surveys of biologists and knowledgeable individuals in that region. These results suggest that red squirrels have probably expanded their range over the last 3 decades to the west by approximately 25 km; apparently using the riparian forests in the Kankakee and Iroquois River watersheds as primary movement corridors. Grasslands, agricultural fields, and highways may slow dispersal, but they have not blocked range expansion. Finally, although I did not quantify the relationship, woodlots inhabited by red squirrels appeared to have fewer gray squirrels than those where red squirrels were apparently absent.

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Table 1. Results and locations of playback surveys in northeastern Illinois.

| # | Site surveyed | County | Squirrels present |
|---|---|---|---|
| 1 | Goose Lake Prairie State Natural Area | Grundy | X |
| 2 | Gebhart Woods & section of I&M Canal | Grundy | |
| 3 | Iroquois Co. State Wildlife Area | Iroquois | X |
| 4 | Hooper Branch Savanna | Iroquois | |
| 5 | Del Rey DOT site | Iroquois | X |
| 6 | Savickis private property | Iroquois | X |
| 7 | Bronson private property | Iroquois | X |
| 8 | Specchio private property (near Loda) | Iroquois | |
| 9 | Private land near Loda | Iroquois | |
| 10 | Private property near Woodland | Iroquois | |
| 11 | State-owned property (old Girl Scout camp) | Iroquois | |
| 12 | Iroquois Woods | Kankakee | X |
| 13 | Kankakee River State Park selected woodlots | Kankakee | X |
| 14 | TNC property: Pembroke township | Kankakee | |
| 15 | Island Park, Momence | Kankakee | X |
| 16 | Sweet Fern private property | Kankakee | |
| 17 | Aroma Park Forest Preserve | Kankakee | |
| 18 | Momence Wetlands selected woodlots | Kankakee | |
| 19 | TNC property: Bentley/Crawford | Kankakee | |
| 20 | TNC property: Tallmadge | Kankakee | |
| 21 | Waldon Arboretum | Kankakee | X |
| 22 | TNC property | Kankakee | |
| 23 | Gooseberry Island Nature Preserve | Kankakee | |
| 24 | Bourbonnais Geological Area | Kankakee | X |
| 25 | Island in Kankakee River State Park | Kankakee | |
| 26 | Illini State Park | LaSalle | |
| 27 | Starved Rock State Park | LaSalle | |
| 28 | Matthiessen State Park | LaSalle | |
| 29 | White Pines Forest State Park | Ogle | |
| 30 | Middle Fork Wildlife Area selected woodlot | Vermilion | |
| 31 | Kickapoo State Park selected woodlot | Vermilion | |
| 32 | Raccoon Grove Forest Preserve | Will | |
| 33 | Des Plaines Fish and Wildlife Area | Will | X |
| 34 | Messenger Woods Nature Preserve | Will | |
| 35 | Hitts Siding Nature Preserve | Will | |
| 36 | Laughton Preserve | Will | |
| 37 | Thorn Creek Woods Nature Preserve | Will | |
| 38 | Hickory Creek Preserve | Will | |
| 39 | Hammel Woods | Will | |
| 40 | Rock Run Preserve | Will | |

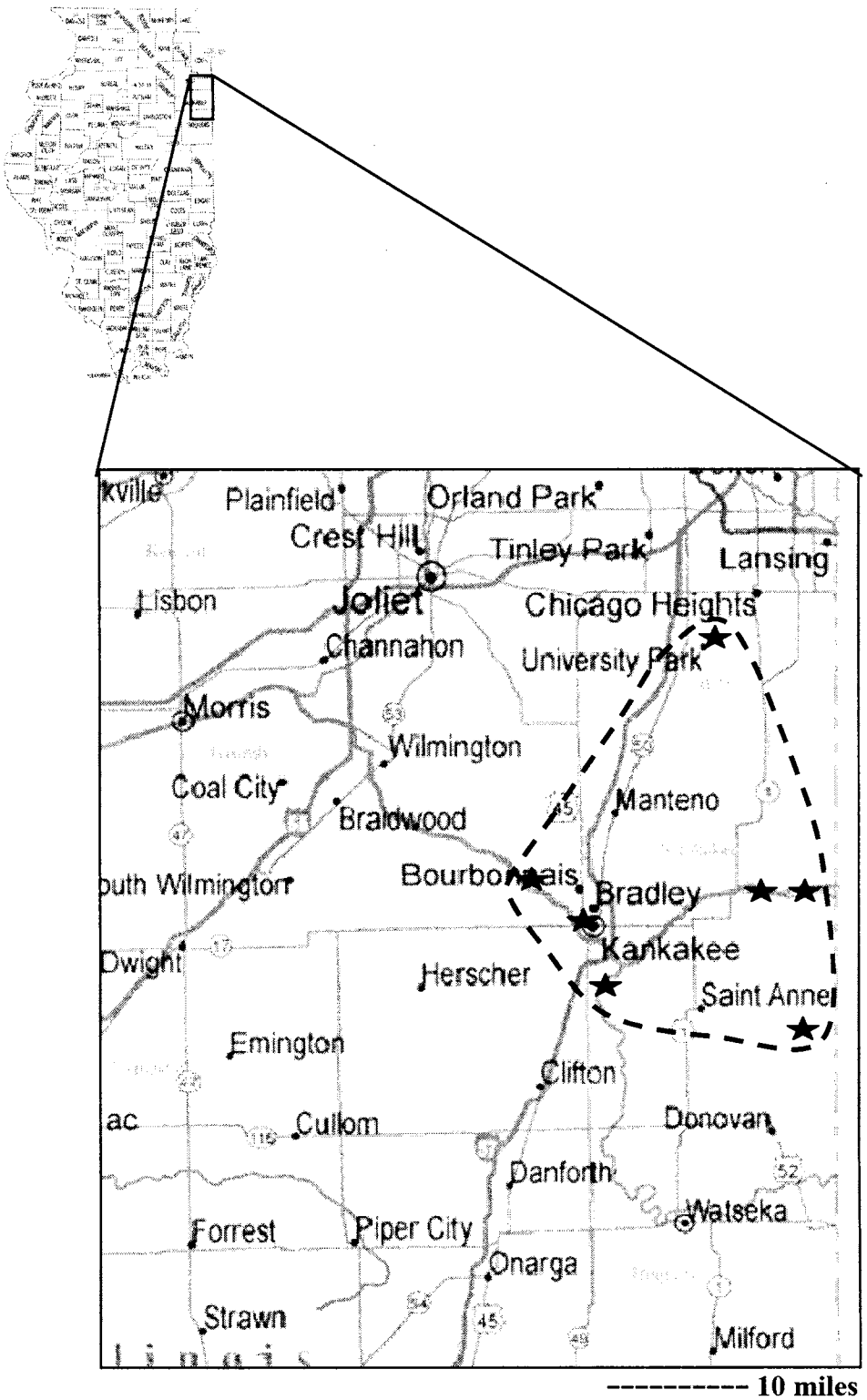
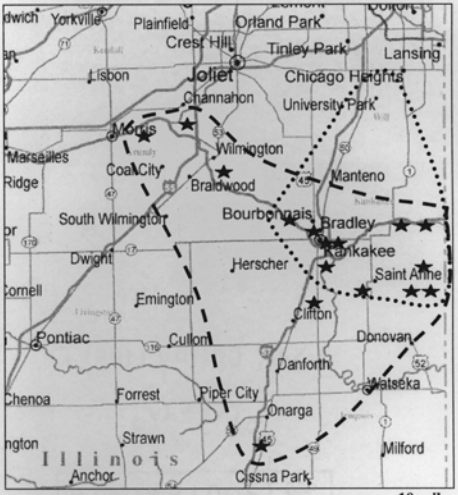



Figure 1. Map illustrating the approximate known distribution of red squirrels prior to my first field season. Stars indicate confirmed locations.




LIST OF RED SQUIRREL LOCATIONS

- Kankakee River State Park
- Waldon Arboretum
- Island Park, Momence
- Momence Wetlands (reported)
- Iroquois Woods (aka Campbell's Woods)
- Iroquois County State Wildlife Area
- Hahn property: Pembroke township (reported)
- Bronson private property (SW of St. Anne)
- Del Ray DOT site
- Perry Farm, Kankakee (reported)
- Savickis private property
- Des Plaines Fish and Wildlife Area
- Goose Lake Prairie State Natural Area
- Custer Park (reported)
- Woodlot by Clifton High School (reported)
- Bourbonnais Geological Area

Figure 2. Map showing the approximate geographic ranges of red squirrels in Illinois before and after my study. Stars indicate current known locations occupied by red squirrels. The dotted line indicates the known range prior to my study; the dashed line indicates the known range after my study.